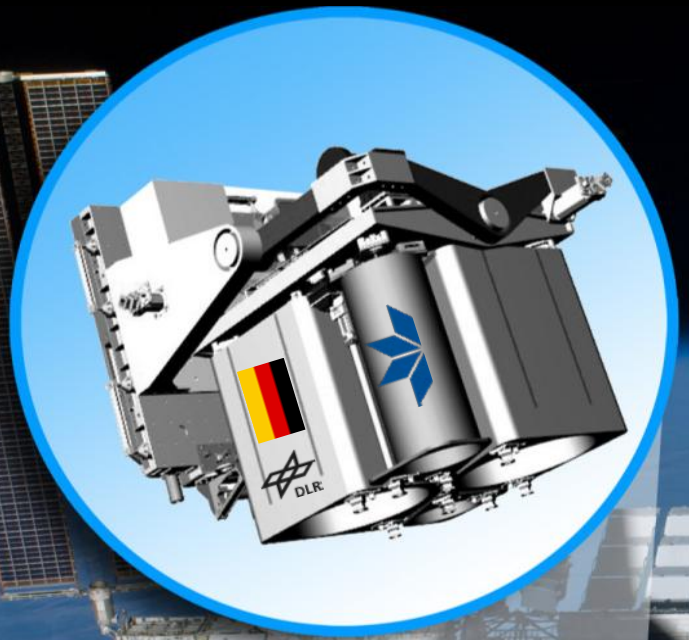
The Hyperspectral Sensor DESIS on MUSES: Processing and Applications

R. Müller, D. Cerra, E. Carmona, K. Alonso Gonzalez,
M. Bachmann, B. Gerasch, H. Krawczyk

German Aerospace Center (DLR), Earth Observation Center (EOC),
D-82234 Wessling, Germany
daniele.cerra@dlr.de

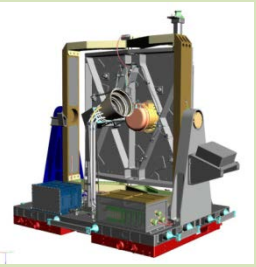
Teledyne and DLR have partnered to build and operate the DLR Earth Sensing Imaging Spectrometer (DESIS) from the Teledyne-owned Multi-User System for Earth Sensing (MUSES) Platform on the ISS



MUSES provides accommodations for two large and two small hosted payloads and core services like

- Position via GPS (1 Hz)
- Attitude via Startracker + MIMU (10 Hz)
- Master time (~250 µsec)
- 2 Gimbals
  (±25° for/back; 45° backboard; 5° starboard)
- 225 Gbit / day Ku band downlink

The hyperspectral sensor **DESIS** is currently the first payload



MUSES@**ISS**
~ 400 km altitude
51.6° orbit inclination
~ 90% of populated Earth
~ 3-5 days average cadence

Teledyne and DLR have partnered to build and operate the DLR Earth Sensing Imaging Spectrometer (DESIS) from the Teledyne-owned Multi-User System for Earth Sensing (MUSES) Platform on the ISS

DLR

Teledyne

NASA

MUSES provides accommodations for two large and
s like

board)

MUSES@**ISS**
~ 400 km altitude
51.6° orbit inclination
~ 90% of populated Earth
~ 3-5 days average cadence

DESIS – Characteristics

Parameters	DESIS	EnMAP
Orbit	ISS (~ 400km)	Polar, Sun synchronous (~ 650km)
FOV	4.4°	2.63°
GSD @ Nadir	30 m @ 400 km (reference height)	30 m
Swath	30 km	30 km
Spectral Range	400 - 1000 nm	400 - 2450 nm
Spectral Sampling	2.55 nm for 235 bands Programmable binning on-orbit (up to 4x)	6.5 nm (420 nm - 1000 nm; VNIR) 10 nm (900 nm - 2450 nm; SWIR)
Spectral Channels	235 @ no binning 117 @ 2 band binning 78 @ 3 band binning 58 @ 4 band binning	94 @ VNIR 134 @ SWIR
SNR @ 550 nm	205 sampled at 2.55 nm 406 binned to 10.21 nm	500@495 nm 170@2200 nm (Albedo 0.3, SZA 30°)
Spatial Pixels	1024	1000
Capacity [max. km/year]	850,000	1,800,000
Pixel Quantization	12 bit plus 1 bit for low and high gain setting	14 bits
Pointing Unit	BRDF mode: 11 measurement positions ±15° (every 3°) FMC : Rotation speed 0,6°/sec or 1,5°/sec	N/A

DESIS – Products and Processing Chain

Products:

- **Level 0 (L0)**
  - Raw data
- **Level 1A (L1A)**
  - L0 data with correction and calibration computed and appended
- **Level 1B (L1B)**
  - Top of Atmosphere (TOA) radiance (W.m-2.sr-1.µ m-1)
- **Level 1C (L1C)**
  - Level 1B data ortho-rectified, re-sampled to a specified grid
- **Level 2A (L2A)**
  - Earth located ground surface reflectance (i.e. after atmospheric corrections)
  - Takes smile effect into account

Processors:

- Working on tiled data: 1024 x 1024 pixels (~ 900 km^2)
- Fully automated,
- Run ‘on-request’ over archived data (L1A)
- Two instances: one at TBE, one at DLR

DLR

Processing – Quality Layers and Metadata

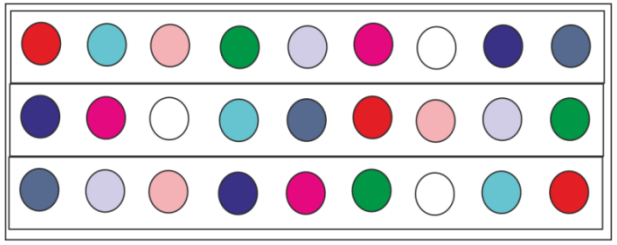
Quality Layer (Geotiff)	L1B	L1C	L2A
Dead pixels	X	X	X
Abnormal pixels	X	X	X
Too high radiance level	X	X	X
Too low radiance level	X	X	X
Shadow			X
Land			X
Water			X
Haze over land			X
Haze over water			X
Cloud over land			X
Cloud over water			X
Aerosol optical thickness			X
Perceptible water vapour			X
Band cross-correlation	X	X	X
Bad columns	X		
Bad lines	X		

- Dead Pixels:
  - generated through calibration
- Abnormal pixels:
  - Generated by comparison between measured radiances and calibration
- Data Screening
  - Temperatures, Voltages, Currents
- Geometric accuracy
  - Subset of matching points with reference
- Bad columns/lines:
  - Generated by statistical tests
- L2A Thematic quality layers:
  - Generated by ATCOR

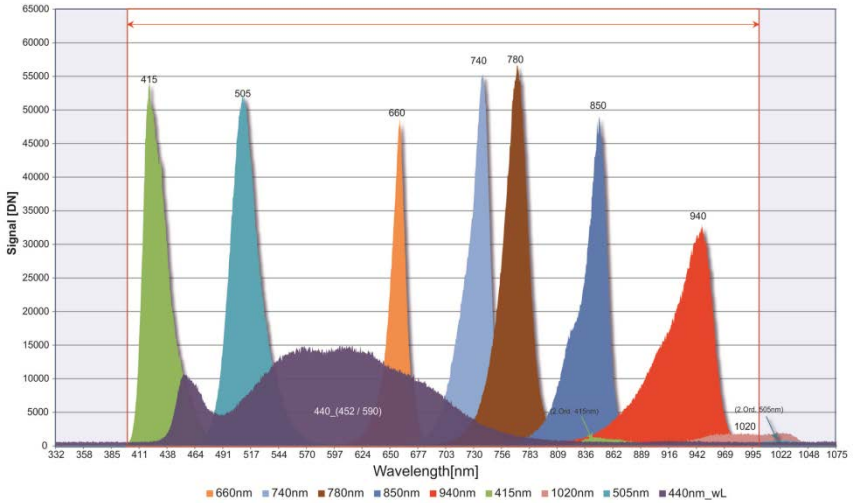
DLR

Calibration

- Laboratory calibration (HSI+Calibration Unit)
- In-flight calibration*
  - Dark Signal measurements
    (before / after each datatake)
  - Calibration Unit for radiometric,
    linearity and spectral measurments
  - Ground Control Points for geometric
    sensor model adjustments



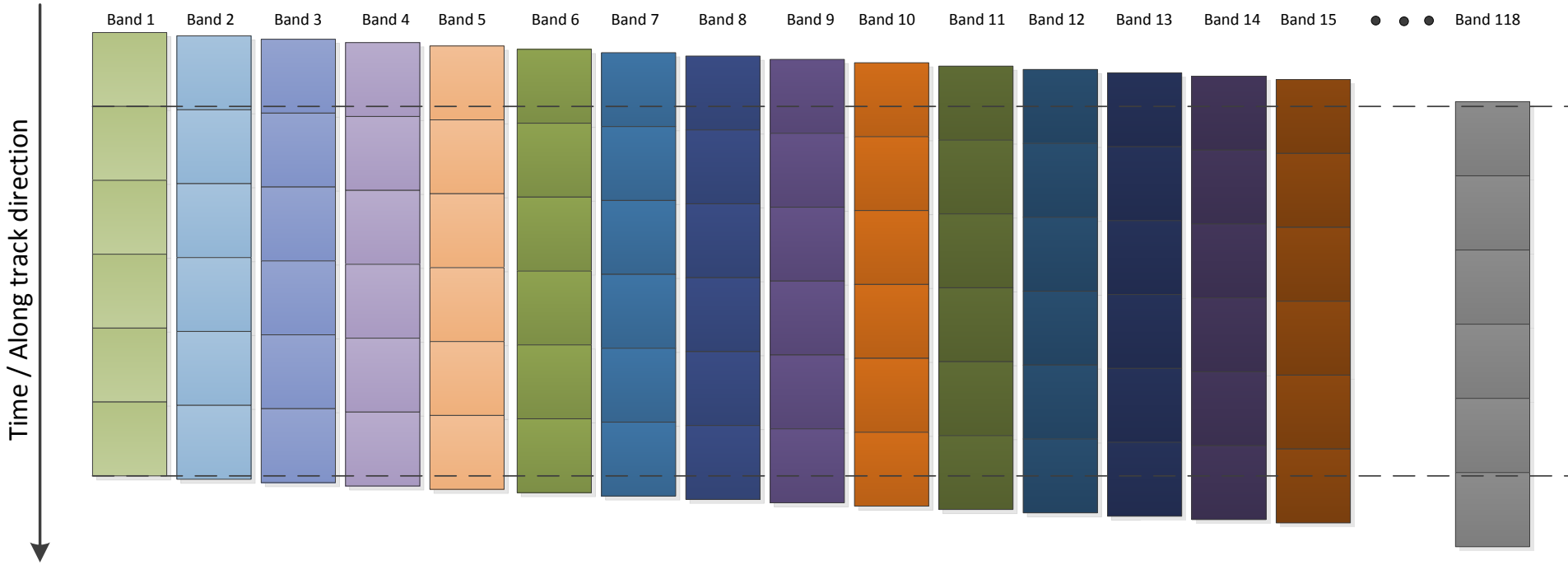
Calibration Unit: Each line with eight monochromatic LED and one white LED (2000 h burn-in time)



** 0.1 Kelvin thermal stabilized*

Image Acquisition: Rolling Shutter

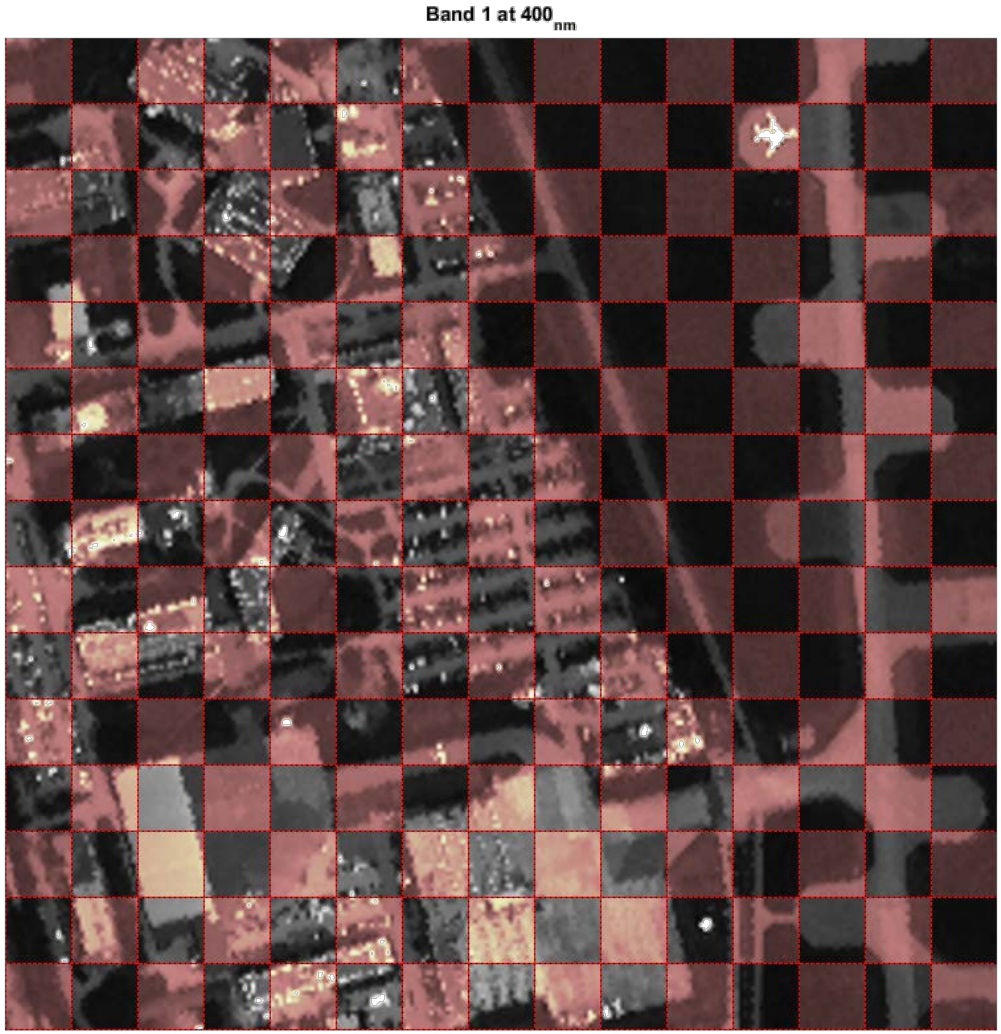
- DESIS will be the first multiband spaceborne sensor featuring a rolling shutter
- Each consecutive band is observed at a slightly delayed position on ground



- Need to re-sample data to have all wavelength registered values at the same position on ground

Simulation of Rolling Shutter in a 15 x 15 DESIS subset

DESIS grid is → overlaid in red

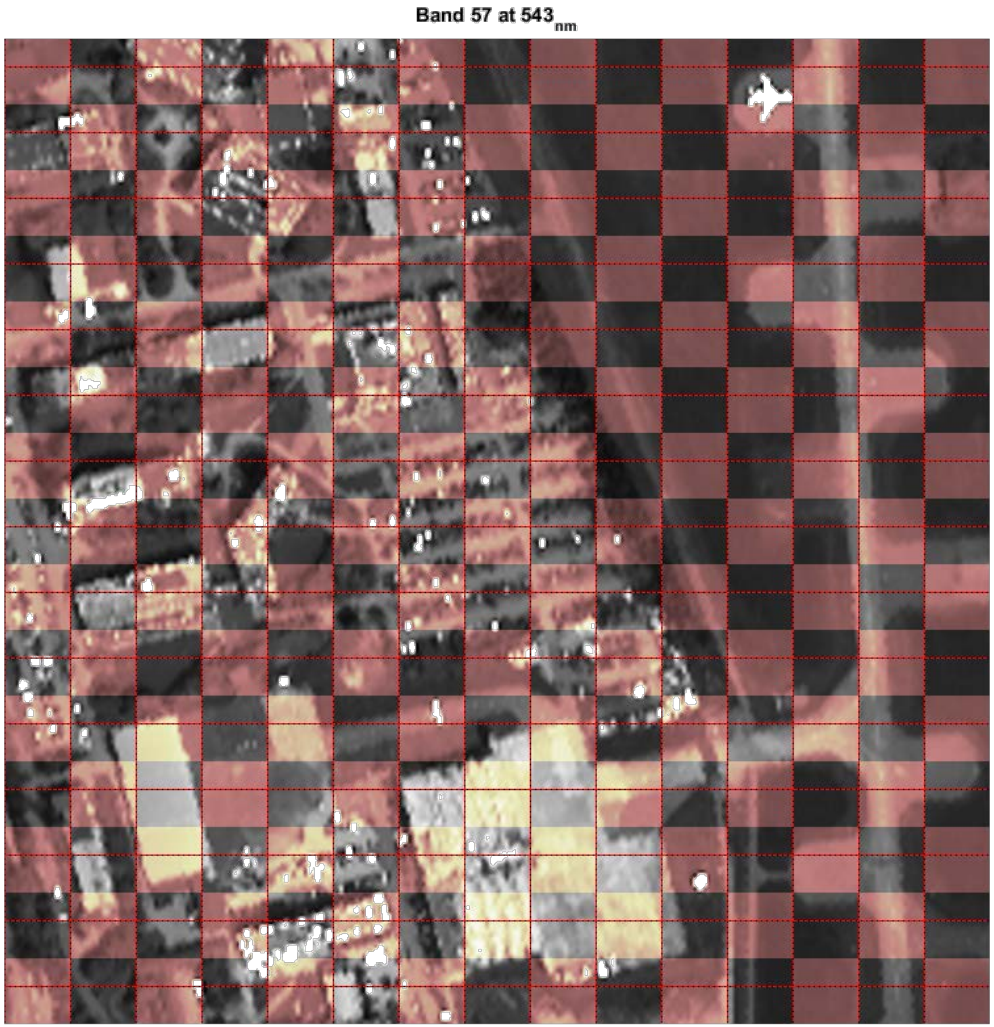


← HySpex image is shown

← In black/white the measured area for one pixel in one band

Simulation of Rolling Shutter in a 15 x 15 DESIS subset

DESIS grid is → overlaid in red

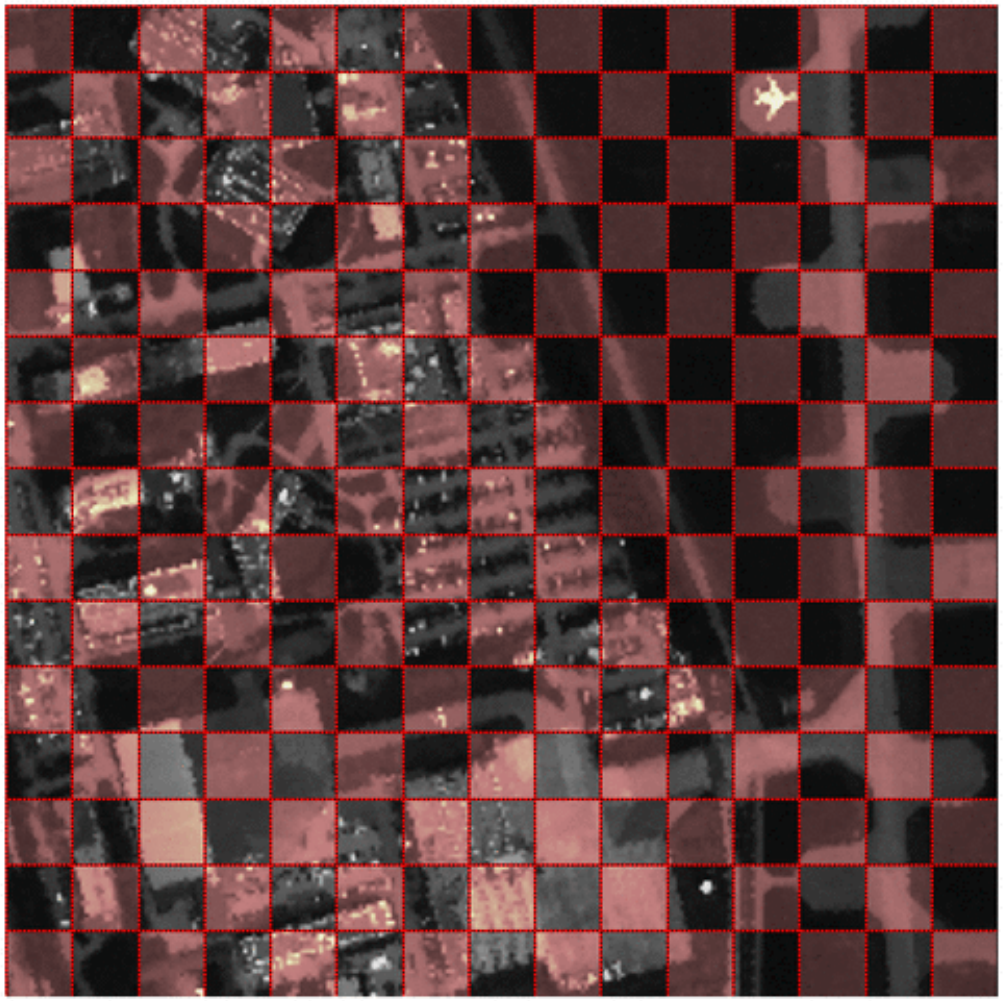


← HySpex image is shown

← In black/white the measured area for one pixel in one band

Simulation of Rolling Shutter in a 15 x 15 DESIS subset

DESIS grid is → overlaid in red



Band 1 at 400 nm

← HySpex image is shown

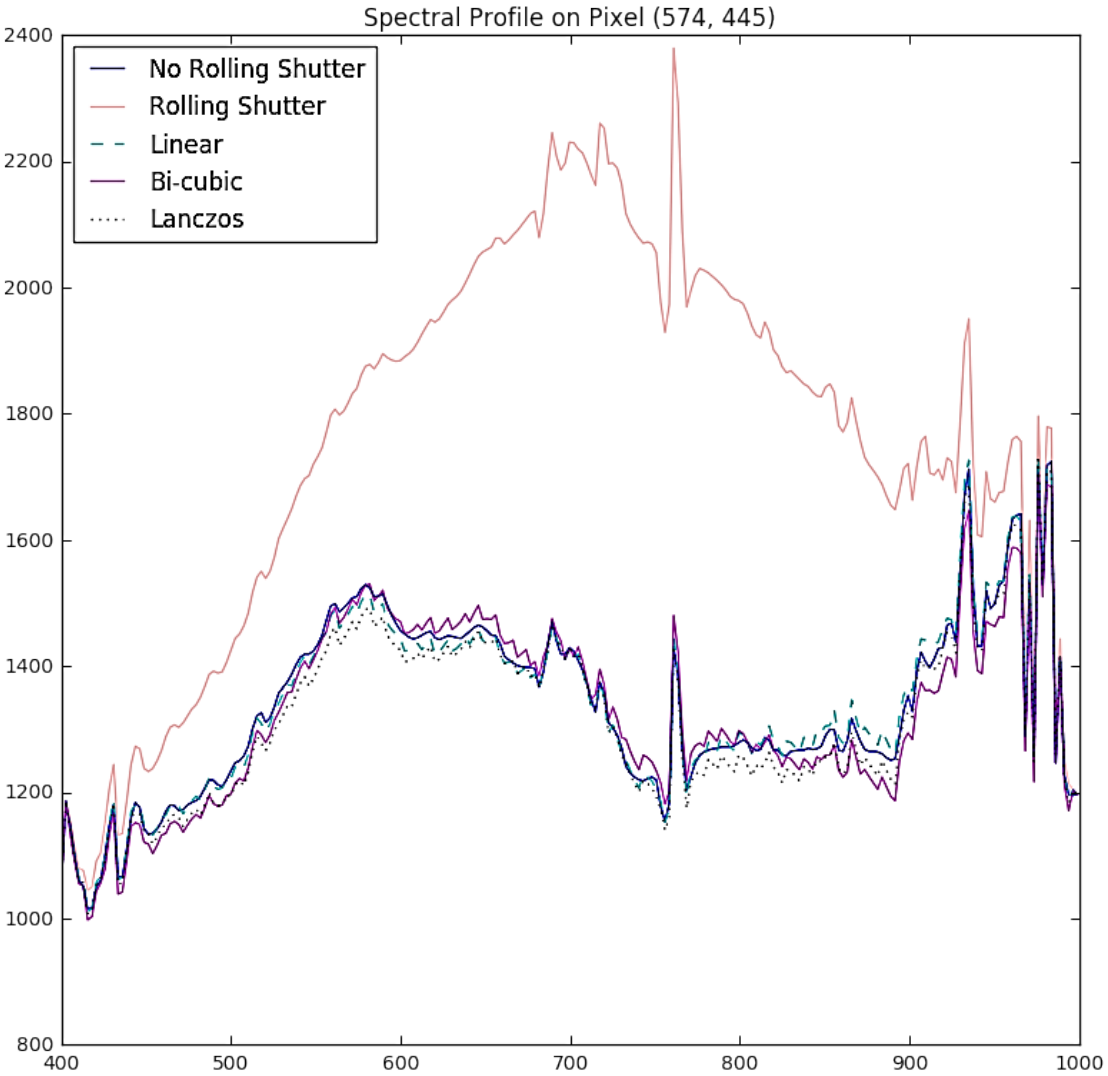
← In black/white the measured area for one pixel in one band

DLR

Rolling Shutter: Problem or Opportunity?

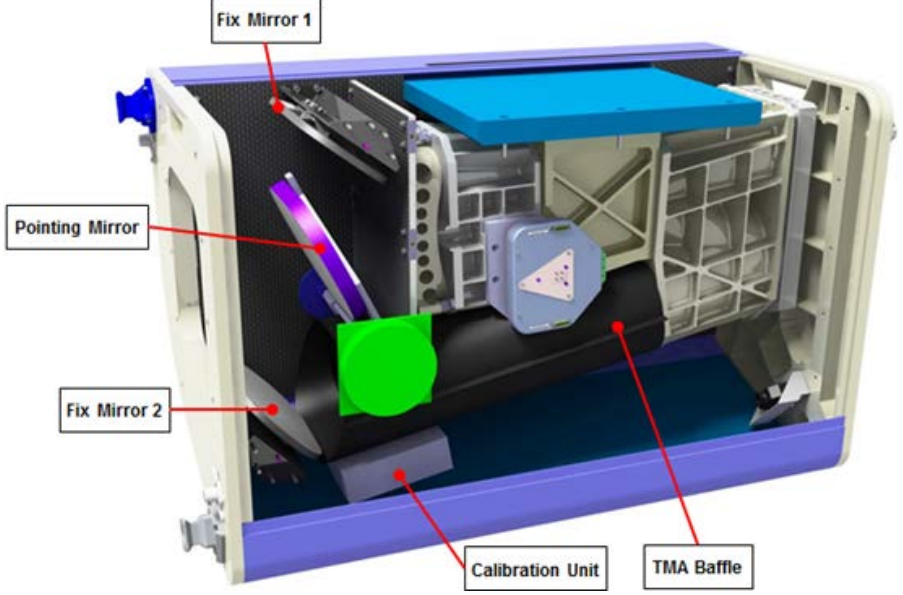
- Both!
- Spectral distortions are introduced, but…
- Opportunity for the development of novel algorithms under research:
    - Super-resolution techniques
    - Ad hoc spectral correction
- The high spectral resolution will help in mitigating negative effects

Example: correction of simulated data



DLR

Applications / Science (1/3)



- DESIS Specificities
  - Non Polar orbit
  - Multiple viewing geometries allowed
  - ‘Science’ experimental acquisition modes: platform / pointing mirror rotations
    - BRDF or Stereoscopic acquisitions
    - Forward motion compensation Mode (FMC)
      - E.g. Atmospheric correction research
      - E.g. BRDF
  - Night-time imagery is possible
  - As soon as other sensors are placed on MUSES:
    - Potential sensor-fusion approaches
    - Potential multi-modal observations at the same time

DLR

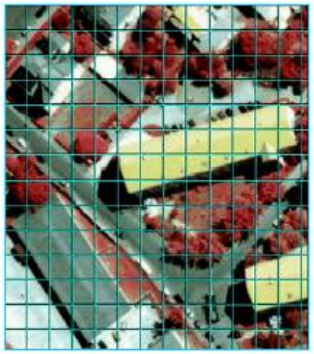
Applications / Science (2/3)

DESIS could, as any HSI, be used for:

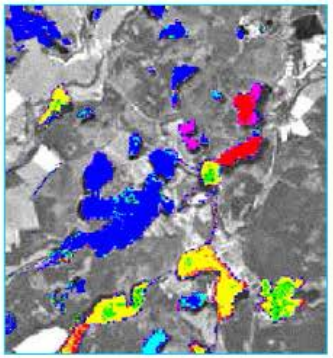
- Mid- and long-term environmental monitoring of mining resource districts (environmental acidification, restoration assessment)
- Soil degradation (indicators, pollution, salinization)
- Vegetation monitoring (stress parameters)
- Inland waters (chlorophyll, pollution, bathymetry, water content models)
- Preparation for the German EnMAP mission launched in 2019 (DLR establish the DESIS and the EnMAP Ground Segment with similar functionalities)

management of agricultural and forest ecosystems

hazard assessment



urban development



inland water

dryland degradation

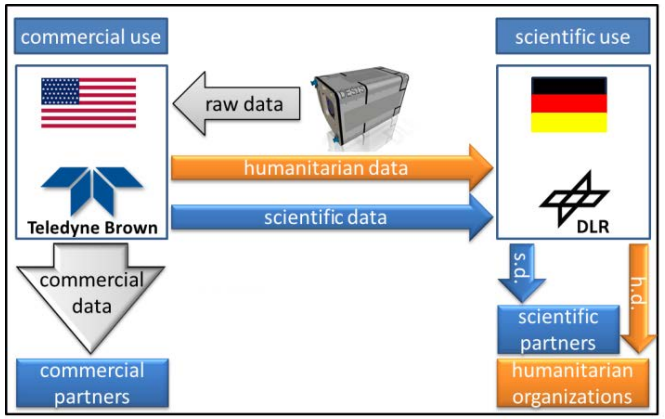
DLR

Applications / Science (3/3)

Data from DESIS could also be used as a support for developing innovative methods for processing hyperspectral data:

- Spectral unmixing techniques (linear & non-linear methods)
- De-noising techniques (especially at wavelengths close to 400 nm for water applications)
- Improvements of hyperspectral data classification methods (deep learning, compressive sensing / sparse reconstruction, synergetics)
- Derivation of geophysical parameters
- Fusion of hyperspectral (DESIS) and multispectral (WV-2/3, Sentinel-2,…) for resolution enhancement keeping the spectral integrity (not only pan-sharpening)
- …

Data Policy



- DESIS is to be operated by Teledyne (TBE):
  - TBE will receive the raw data
  - TBE has the exclusive right to license or transfer image data for commercial use.
- For scientific and humanitarian purposes, DLR has the right to:
  - Task DESIS, 2000 minutes/year
  - Request archived data
- For scientific purposes only:
  - DLR can share DESIS scientific data with other scientific organizations:
  - Scientific use includes:
    - basic and application oriented research,
    - projects by national and international educational or research institutions or by governmental institutions,
    - development and demonstration of future applications for scientific and/or operational use and
    - preparation and execution of government-funded education, research and development programs.

Summary

- The DESIS Instrument will be used to:
  - Enable scientific RESEARCH
  - Expand HUMANITARIAN response
  - Provide COMMERCIAL value

- DESIS to be installed in mid 2018:
  - Max. of 235 spectral bands in the VNIR domain (2.55 nm spectral resolution)
  - 30m GSD, 30km swath
  - Design life time 5 years
  - Data (non-experimental) processed at user's request up to L2A data
  - Different experimental observation modes will be offered
  - Rolling shutter acquisition

- TBE is providing commercial data, but:
  - Scientific and humanitarian use is granted to DLR
  - Data can be shared with DLR partners for scientific use

Thank you for your attention!

Vicarious Validation

Three main radiometric / spectral validation activities:

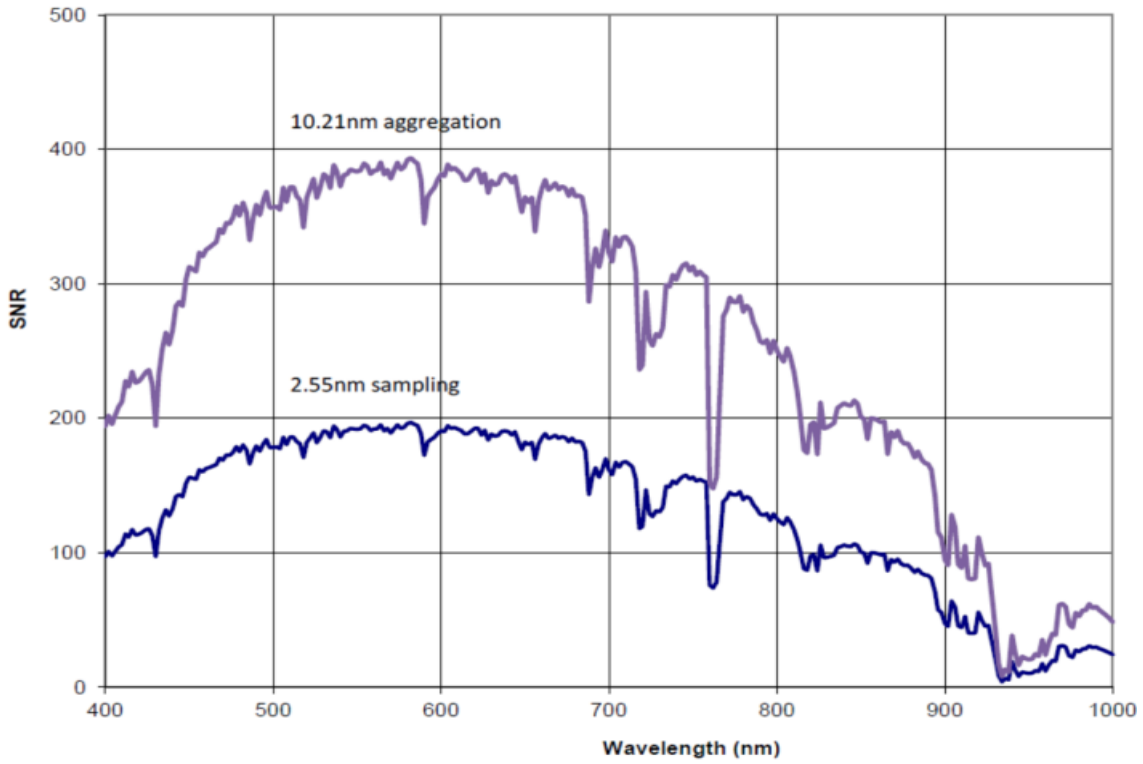
- Data validation over homogeneous areas:
  - E.g. CEOS LandNet / PICS sites
  - L1B to L2A data
  - Comparison with other space-borne sensors (e.g. HISUI)
- Airborne cross-validation
  - L1B to L2A data cross comparison
  - Comparison of different atmospheric comparisons / processing chains
- Local homogeneous areas in heterogeneous scenes
  - Estimation of SNR over the complete radiometric range

Two main geometric validation:

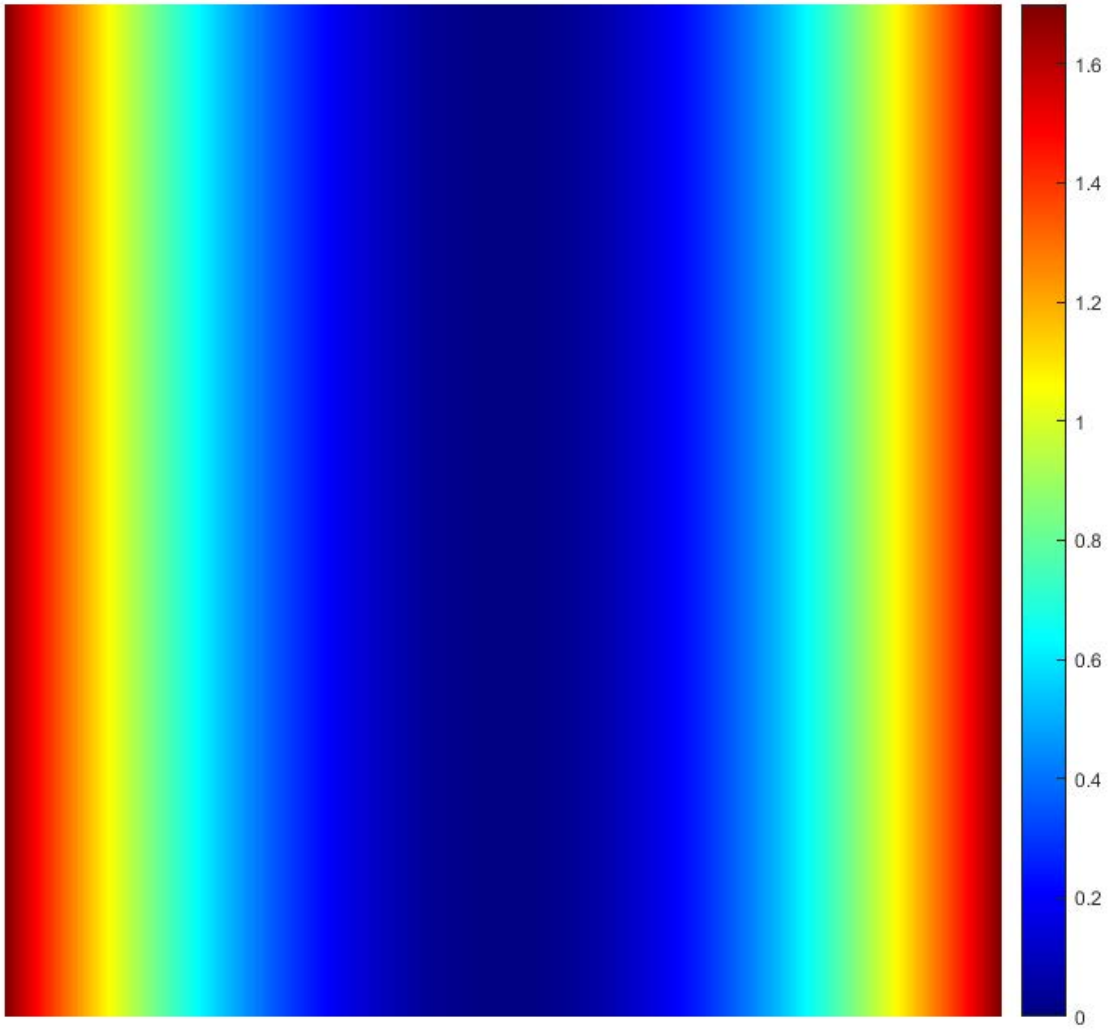
- Image matching with higher accuracy imagery (e.g. LandSat-8 Pan)
- Band to band registration checks

Signal-to-Noise Ratio

Signal-to-Noise Ratio (SNR) for the spectral sampling of 2.55 nm (lower curve) and the 4x binning with 10.21 nm spectral sampling (upper curve). Simulation based on Modtran with standard mid latitude summer atmosphere (Albedo: 0.3; Sampling 0.2 nm)

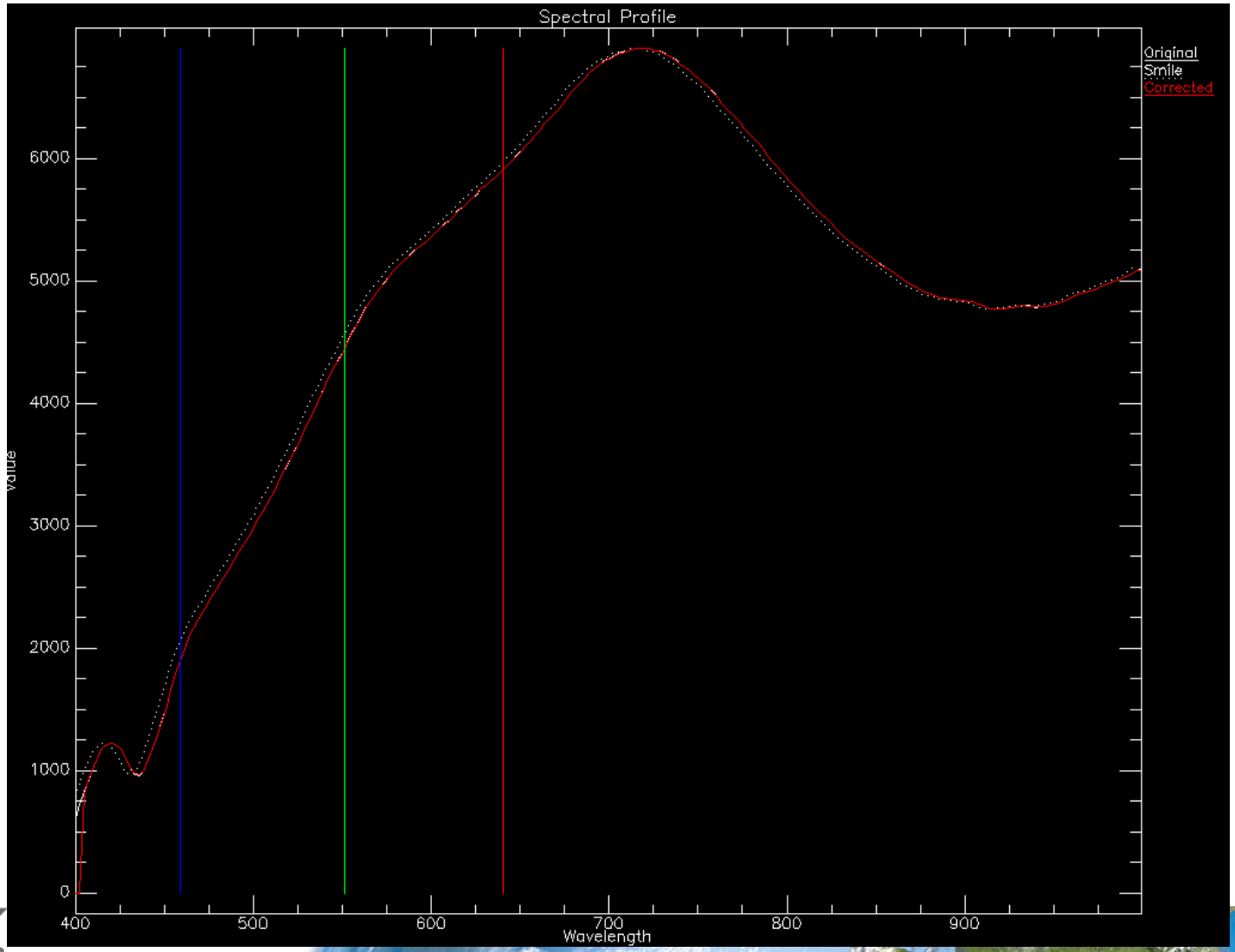


Smile in pixels (any wavelength)



Smile Correction

Unit: reflectance x 10000
Dashed - - - : maximum smile
Red: Smile correction



DLR